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**NON-PROVISIONAL APPLICATION FOR U. S. PATENT UNDER 37 CFR 1.53(b)  
TRANSMITTAL FORM**

Attorney Docket No. TI-28674

Assistant Commissioner for Patents  
Washington, D. C. 20231

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Inventor(s): **Michael A. Lamson**  
**Navinchandra Kalidas**

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*Nancy Thornton*  
Nancy Thornton

For: **STRUCTURE AND METHOD OF HIGH PERFORMANCE TWO LAYER BALL GRID ARRAY  
SUBSTRATE.**

Enclosed are:

- 5 Sheets of formal drawings and 30 pages of Specification (including Abstract)
- x A Declaration/Power of Attorney
- x Assignment with form PTO 1595

Please amend the specification by inserting before the first line the sentence:

This application claims priority under 35 USC § 119 based upon **Provisional Patent  
Application number 60/147,596, filed 08/06/99.**

FEE CALCULATION					FEE
	NUMBER		NUMBER EXTRA	RATE	BASIC FEE \$ 690.00
Total Claims	29	-20 =	9	X \$22 =	\$198.00
Independent Claims	4	- 3 =	1	X \$82 =	\$82.00
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**Date: August 1, 2000**

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August 1, 2000

**VIA EXPRESS MAIL**

EL617118328US

Assistant Commissioner for Patents  
Washington, D.C. 20231

Re: Patent Application For  
**STRUCTURE AND METHOD OF HIGH PERFORMANCE TWO LAYER BALL  
GRID ARRAY SUBSTRATE.**  
Attorney Docket No. TI-28674  
Our File: 1000-2083

Dear Sir:

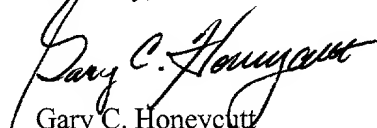
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Sincerely,

  
Gary C. Honeycutt  
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Enclosure



STRUCTURE AND METHOD OF HIGH PERFORMANCE  
TWO LAYER BALL GRID ARRAY SUBSTRATE

FIELD OF THE INVENTION

5           The present invention is related in general to the field of semiconductor devices and processes and more specifically to structure, materials and fabrication of high performance plastic ball-grid array packages designed for flip-chip assembly.

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DESCRIPTION OF THE RELATED ART

Ball Grid Array (BGA) packages have emerged as an excellent packaging solution for integrated circuit (IC) chips with high input/output (I/O) count. BGA packages use sturdy solder balls for surface mount connection to the "outside world" (typically plastic circuit boards, PCB) rather sensitive package leads, as in Quad Flat Packs (QFP), Small Outline Packages (SOP), or Tape Carrier Packages (TCP). Some BGA advantages include ease of assembly, use of surface mount process, low failure rate in PCB attach, economic use of board area, and robustness under environmental stress. The latter used to be true only for ceramic BGA packages, but has been validated in the last few years even for plastic BGAs. From the standpoint of high quality and reliability in PCB attach, BGA packages lend themselves much more readily to a six-sigma failure rate fabrication strategy than conventional devices with leads to be soldered.

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A BGA package generally includes an IC chip, a multi-layer substrate, and a heat spreader. The chip is generally mounted on the heat spreader using a thermally conductive adhesive, such as an epoxy. The heat spreader provides a low resistance thermal path to dissipate thermal energy, and is thus essential for improved thermal performance during device operation, necessary for consistently good electrical performance. The heat spreader is generally construed of copper and may include gold plating -- representing an expensive part of the package. Further, the heat spreader provides structural and mechanical support by acting as a stiffener, adding rigidity to the BGA package, and may thus be referred to as a heat spreader/stiffener.

One of the substrate layers includes a signal "plane" that provides various signal lines, which can be coupled, on one end, to a corresponding chip bond pad using a wire bond (or to a contact pad using flip-chip solder connection). On the other end, the signal lines are coupled with a solder "ball" to other circuitry, generally through a PCB. These solder balls form the array referred to in a BGA. Additionally, a ground plane will generally be included on one of the substrate layers to serve as an active ground plane to improve overall device performance by lowering the inductance, providing controlled impedance, and reducing cross talk. These features become the more important the higher the BGA pin count is.

In contrast to the advantages of the BGA packages, prevailing solutions in BGA packages have lagged in performance characteristics such as power dissipation and the ability to maintain signal integrity in high speed operation necessary for devices such as high speed digital

signal processors (DSP) and mixed signal products (MSP).  
Electrical performance requirements are driving the need to  
use multi-layer copper-laminated resin substrates  
(previously ceramic). As clock frequencies and current  
5 levels increase in semiconductor devices, the packaging  
designs are challenged to provide acceptable signal  
transmission and stable power and ground supplies.  
Providing stable power is usually achieved by using  
multiple planes in the package, properly coupled to one  
10 another and to the signal traces. In many devices,  
independent power sources are needed for core operation and  
for output buffer supply but with a common ground source.

As for higher speeds, flip chip assembly rather than  
wire bonding has been introduced. Compared to wire bonding  
15 within the same package outline, flip chip assembly offers  
greatly reduced IR drop to the silicon core circuits;  
significant reduction of power and ground inductances;  
moderate improvement of signal inductance; moderate  
difference in peak noise; and moderate reduction in pulse  
20 width degradation.

In order to satisfy all these electrical and thermal  
performance requirements, packages having up to eight metal  
layers have been introduced. The need, however, of high  
numbers of layers is contrary to the strong market emphasis  
25 on total semiconductor device package cost reduction. This  
emphasis is driving an ongoing search for simplifications  
in structure and materials, of course with the constraint  
that electrical, thermal and mechanical performances should  
be affected only minimally.

30 The complexity and cost of the BGA packages are also  
influenced by the number of interconnections or vias that  
must be fabricated in the substrate layers to provide a

path to connect each of the solder balls to either the ground plane, the power planes, or desired signal lines of the signal plane. Each via requires the formation of an electrically conductive layer on the internal walls of the via, to ensure a complete electrical path. Generally, the metallization of the internal walls of each via increases the overall complexity. Consequently, multiple vias and multiple substrate layers result not only in higher BGA fabrication costs, but also lower yields.

Analyzing the total package cost shows that the cost of the substrate dominates (usually more than 50%), followed by the heat slug (usually at least 30 %). In order to reduce the substrate cost, however, the number of layers should be reduced. This approach, in turn, seems to greatly endanger the electrical and thermal package performance.

An urgent need has therefore arisen to break this vicious cycle and conceive a concept for a low-cost, yet high performance BGA package structure. Preferably, this structure should be based on a fundamental design concept flexible enough to be applied for different semiconductor product families and a wide spectrum of design and assembly variations. It should not only meet high electrical and thermal performance requirements, but should also achieve improvements towards the goals of enhanced process yields and device reliability. Preferably, these innovations should be accomplished using the installed equipment base so that no investment in new manufacturing machines is needed.

## SUMMARY OF THE INVENTION

According to the present invention, a high-performance, high input/output ball grid array substrate is provided, which is designed for integrated circuit flip-chip assembly and has two patterned metal layers and an intermediate insulating layer.

The insulating layer has a plurality of vias filled with metal, and one of the metal layers attached to each surface. Positioned between the two metal layers, the insulating layer has a thickness and material characteristics suitable for strong electromagnetic coupling between the signal lines and the first metal layer. In this manner, a predetermined impedance to ground is provided, and cross-talk between signal lines is minimized.

The first metal layer provides the electrical ground potential and has a plurality of electrically insulated openings for outside electrical contacts.

The second metal layer has three portions: The first portion is configured as a plurality of signal lines; the second portion is configured as a plurality of first electrical power lines operable at a first potential; and the third portion is configured as a plurality of second electrical power lines operable at a second potential. The first power lines are configured so wide that their combined inductances approximate the inductance of a metal having the size of the total substrate. The second power lines are configured to serve as distributed areas having wide geometries for minimizing self-inductance and merging into a central area supporting the IC chip.

It is an aspect of the invention that the signal lines are distributed relative to the first power lines such that the inductive coupling between them reaches at least a minimum value, providing high mutual inductances and close to zero effective self-inductance. Further, the signal lines are electromagnetically coupled to the ground metal such that cross-talk between signal lines is minimized.

Another aspect of the invention is to provide an outermost insulating layer protecting the exposed surface of the ground layer. This insulating film has a plurality of openings filled with metal suitable for solder ball attachment.

Another aspect of the invention is to provide another outermost insulating layer protecting the exposed surfaces of the signal and power lines. This insulating film has a plurality of openings filled with metal suitable for contacting selected signal and ground lines and chip solder bumps.

Another aspect of the invention is to provide the modeling guidelines for designing the substrate structures and materials such that they are flexible enough to be applied for different semiconductor high-performance device families and a wide spectrum of high speed, high power design and assembly variations.

Another aspect of the invention is to utilize existing semiconductor fabrication processes and to reach the substrate and device goals without the cost of equipment changes and new capital investment, by using the installed fabrication equipment.

Another aspect of the invention is to reduce the thickness of the BGA substrate substantially so that the



BGA device can readily be employed in a variety of new products requiring thin semiconductor components.

Another aspect of the invention is to improve the inherent thermal dissipation to a degree that the use of a  
5 heat slug is no longer mandatory to achieve the required thermal characteristics.

These aspects have been achieved by the computer-implemented method for modeling a high-performance, high I/O ball grid array substrate, and by a method for  
10 fabricating this substrate for integrated circuit flip-chip assembly, suitable for mass production.

The technical advances represented by the invention, as well as the aspects thereof, will become apparent from the following description of the preferred embodiments of  
15 the invention, when considered in conjunction with the accompanying drawings and the novel features set forth in the appended claims.

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## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic and simplified cross section of the Ball Grid Array device having a substrate according to the invention.

FIG. 2 is a simplified perspective view of the first and the second metal layers.

FIG. 3 is a simplified perspective view of the first metal layer as viewed from the bottom.

FIG. 4 is a simplified top view of a portion of the second metal layer, showing the structure of the signal lines.

FIG. 5 is a simplified top view of a portion of the second metal layer, showing the structure of the first power lines.

FIG. 6 is a simplified top view of a portion of the second metal layer, showing the structure of the second power lines.

FIG. 7 is a simplified top view of the second metal layer showing the combined structures of signal lines, first power lines, and second power lines.

FIG. 8 is a flowchart illustrating an exemplary computer-implemented method for electrically modeling the structure of the metal and power lines according to the teachings of the present invention.

FIG. 9 is a flowchart illustrating an exemplary method for forming a ball grid array package substrate according to the teachings of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a simplified and schematic cross sectional view of a portion of the high-performance, high input/output (I/O) Ball Grid Array (BGA) package of the invention, generally designated 100. Using solder bumps 102 in flip-chip technology, the active surface 101a of the integrated circuit chip 101 is attached to openings in the outermost insulating film 111 of substrate 110, facing the active chip surface 101a. Chip 101 is commonly made of silicon and has a thickness typically in the range of about 200 to 375  $\mu\text{m}$ . The number of I/O's typically is in the range from about 100 to 600; approximately one half of these I/O's serve signal lines, the other half is dedicated to power and ground potentials.

The solder bumps 102 connecting the chip I/O's to the substrate 110 are usually small in diameter, typically about 100 to 120  $\mu\text{m}$  with a range of  $\pm 10 \mu\text{m}$ , and comprise attach materials selected from a group consisting of tin, lead/tin alloys, indium, indium/tin alloys, solder paste, and conductive adhesive compounds. Following the flip-chip attachment, any gaps between chip 101 and substrate 110, and also between the solder bumps 102, are filled with a polymeric encapsulant 103. This encapsulant typically is a polymeric precursor mad of an epoxy base material filled with silica and anhydrides, requiring thermal energy for curing to form a polymeric encapsulant.

The encapsulation material 104, surrounding the chip 101 after flip-chip attachment, serves the protection of the mounted chip. Commonly, it is a polymeric material selected from a group consisting of epoxy-based molding compounds suitable for adhesion to the chip, and fluoro-

dielectric compounds supporting high-speed and high-frequency package performance. For molding compounds, standard transfer molding processes are the preferred method of encapsulation in mass fabrication. Over the  
5 passive surface 101b of the chip, the molded material 104a may have a thickness typically in the range from 300 to 500  $\mu\text{m}$ , between the substrate and the heat slug from about 500 to 800  $\mu\text{m}$ .

The heat spreader 105, positioned on the outer  
10 surface of the encapsulation material 104, is optional. Its thickness is typically in the range from about 150 to 300  $\mu\text{m}$ . It enhances heat spreading and heat dissipation and thus the overall thermal performance of the device significantly, but is usually made of copper and thus a  
15 substantial cost contributor. However, based on the outstanding thermal characteristics of the BGA substrate of the present invention, the desired thermal device performance can be achieved even without an additional heat spreader.

20 Solder balls 106 are attached to the plurality of openings in the outermost insulating film 112 of substrate 110. As defined herein, the term solder "balls" does not imply that the solder contacts are necessarily spherical. They may have various forms, such as semispherical, half-  
25 dome, truncated cone, or generally bump. The exact shape is a function of the deposition technique (such as evaporation, plating, or prefabricated units) and reflow technique (such as infrared or radiant heat), and the material composition. The solder balls usually have a  
30 diameter in the range from about 0.1 to 0.4 mm. Several methods are available to achieve consistency of geometrical shape by controlling amount of material and uniformity of

reflow temperature. The solder balls 106 comprise attach materials selected from a group consisting of tin/lead, tin/indium, tin/silver, tin/bismuth, solder paste, and conductive adhesive compounds.

5       The two outermost insulating films 111 and 112 of the substrate serve as protection for the substrate metal patterns and as solder masks. The films preferably are glass-filled epoxies, polyimides, acrylics or other photo-imageable materials suitable as solder masks in the  
10 thickness range from about 50 to 100  $\mu\text{m}$ . The openings for solder bump and solder ball attachments are made of copper including a flash of gold, palladium or platinum, or other wettable and solderable metals.

As FIG. 1 schematically shows, the substrate 110  
15 consists of an insulating layer 113 having a first surface 113a, a second surface 113b, and a plurality of vias 114 filled with metal. The preferred metal is copper, but tungsten or any other electrically conductive materials are suitable. The insulating layer 113 has preferably a  
20 thickness in the range from about 70 to 150  $\mu\text{m}$  and is made of organic material selected from a group consisting of polyimide, polymer strengthened by glass fibers, FR-4, FR-5, and BT resin. The dielectric constant is preferably between 4 and 5.

25       Attached to the first substrate surface 113a is a metal layer 115, configured to provide electrical ground potential. Attached to the second surface 113b is a metal layer 116, configured to provide a plurality of electrical signal lines, further a plurality of first electrical power  
30 lines, and further a plurality of second electrical power lines. The total thickness of the substrate 110 is preferably in the range from about 150 to 300  $\mu\text{m}$ .

The two metal layers 115 and 116 have a thickness preferably in the range of about 7 to 15  $\mu\text{m}$ , and are made, for example, of copper, brass, aluminum, silver, or alloys thereof. Metal layer 115, herein called the "first metal layer", is designed to provide the electrical ground potential. It has a plurality of openings, each having an electrically insulated ring and metal in the core for outside electrical contacts. This core metal is solderable and connects to the solder balls 106.

10 Metal layer 116, herein called the "second metal layer", is designed so that a portion is configured as a plurality of electrical signal lines, a further portion as a plurality of first electrical power lines, and a final portion as a plurality of second electrical power lines.  
15 These portions are illustrated in more detail in FIGs. 4 to 7.

The relation and position of the two metal layers are shown in perspective view in FIGs. 2 and 3. Layer 210 is the first metal layer, providing the electrical ground potential. The plurality of openings is designated 211. When layer 210 is viewed perspectively from the underside, as illustrated in FIG. 3, a plurality of solder balls 311 is attached to the plurality of openings. Solder balls 311 establish the connections of the BGA to the outside world.

25 Referring now to FIG. 2, layer 220 is the second metal layer, providing the plurality of signal lines 221, first power lines 222 and second power lines 223. In the center of the second metal layer 220 is the flip-chip attach area 224, with the larger portion of the metal  
30 belonging to the second power lines. More detail is displayed in FIGs. 4 to 7.

FIG. 4 shows one quadrant, generally designated 400, of the signal line portion of the second metal layer 116. The total signal line portion has three additional quadrants of similar configuration. An individual signal line 401 has a width between 25 and 60  $\mu\text{m}$ . One signal line is spaced to the adjacent signal line by insulating material of a width from about 20 to 50  $\mu\text{m}$ . As FIG. 4 shows, the signal lines terminate at inner endpoints 402 close to the periphery of the chip-to-be-attached, preferably in two staggered rows 402a and 402b of staggered endpoints. The outer endpoints 403 fan out wide in order to serve a distributed array of solder ball connections.

FIG. 5 shows one quadrant, generally designated 500, of the portion of the first power lines of the second metal layer 116. The total portion of the first power lines has three additional quadrants of similar configuration. An individual power line 501 has a width from about 200 to 500  $\mu\text{m}$ . It is an important aspect of the present invention that the first power lines are configured so wide that their combined inductances approximate the inductance of a metal which would have the size of the total substrate. As FIG. 5 shows, the first power lines terminate at inner endpoints 502 close to the periphery of the chip-to-be-attached. The outer endpoints 503 fan out wide in order to serve a distributed array of solder ball connections. By way of example, the first power lines may be at an applied potential of 3.0 V.

It is further an important aspect of the present invention that the signal lines of FIG. 4 are positioned in a proximity of about 20 to 50  $\mu\text{m}$  to the first power lines of FIG. 5, thus providing strong electromagnetic coupling,

high mutual inductance and minimized effective self-inductance.

It is further an important aspect of the present invention that the signal lines are positioned to provide  
5 strong electromagnetic coupling to power and ground lines and thus minimal coupling, or cross-talk, between the signal lines.

It is further an important aspect of the present invention that the signal lines are distributed relative to  
10 the first power lines such that the inductive coupling between them reaches at least a minimum value, providing high mutual inductances and minimized effective self-inductance.

FIG. 6 shows all four quadrants, generally  
15 designated 600, of the portion of the second power lines of the second metal layer. These second power lines are structured as distributed areas 601 having wide geometries for minimizing self-inductance; these areas may, for instance, utilize the four corners of the package. The  
20 second power lines merge into a central area 602 supporting a large number of chip solder bumps. By way of example, the second power lines may be at a 1.8 V applied potential.

In FIG. 7, the three portions of the second metal layer, detailed in FIGs. 4, 5 and 6, are combined and  
25 displayed for one quadrant in order to illustrate the complex interrelated positioning of the signal lines, first power lines, and second power lines according to the invention. The three remaining quadrants of the first metal structures, not shown in FIG. 7, are analogous to the  
30 one quadrant shown relative to the combination of signal and first power lines.



FIG. 8 is a flowchart illustrating an exemplary computer-implemented method 800 for modeling a high-performance, high I/O ball grid array substrate for IC flip-chip assembly according to the teachings of the present invention. Method 800 begins at step 802 by  
5 collecting the inputs of a first and a second metal layer, all of substantially equal areas. The first metal layer provides electrical ground potential.

The majority of the modeling concerns the three  
10 portions of the second metal layer. The method proceeds next to step 804 where the I/O count of the signal lines of the second metal layer is determined. With the I/O input at step 806, the widths and layout of the signal lines are selected. Based on this selection, the resulting impedance  
15 levels of the signal lines are modeled at step 808. Further, the signal lines are electromagnetically coupled to the ground potential applied to the first metal layer; using this coupling, the cross talk between the signal lines is modeled with the goal of minimizing the cross  
20 talk.

At step 810, details of the first power lines (operable at a first electrical potential, for instance 3.0 V) of the second metal layer are added to the modeling. The plurality of the signal lines is routed in conjunction  
25 with the plurality of the first power lines with the goal of providing at least a minimum inductive coupling between signal and power lines. This goal strives to obtain high mutual inductance and to minimize effective self-inductance. If the result of this modeling step is not  
30 satisfactory, the widths of the signal lines are modified in step 809. They are fed back as improved inputs to step 808 in order to repeat the impedance modeling, and then to

step 810 in order to repeat the signal and power lines routing and distribution.

After completing the relative positioning of signal and first power lines, achieving high mutual inductances and minimized effective self-inductance, the widths of the first power lines are maximized in step 812. The goal is to configure the first power lines so wide that their combined inductances approximates the inductance of a metal having the area size of the total substrate.

At steps 814 and 816, the coupling between signal lines and first power lines is further modeled, especially by simulating electrical noise. If the relative line distribution does not exhibit enough insensitivity or suppression of noise, the first power lines are rerouted relative to the signal lines to reduce noise (step 815). The rerouted line distribution is fed back to step 812 as a revised input for maximizing the widths of the first power lines.

At step 818, the plurality of second power lines (operable at a second electrical potential, for instance 1.8 V) of the second metal layer is added to the modeling. The second power lines are modeled to serve as distributed areas having wide geometries so that self-inductance is minimized. The second power lines merge into a central area, which serves to support the IC chip. The maximized widths of the second power lines are used as inputs for step 820, the modeling and simulation of the total package.

Additional inputs for step 820 are the structure, thickness, and material characteristics of the insulating layer positioned between the first and second metal layers. The goal of the modeling is to provide strong electromagnetic coupling between the signal lines and the

first metal layer in order to reach a predetermined impedance to ground (for instance, 50 ohms) and to minimize cross talk between signal lines.

If these goals are not achieved satisfactorily, the layout of signal lines and first and second power lines are modified in step 822 and the new layout is fed back as improved input to the modeling of the total package in step 820. The final output of the electrical modeling is displayed in step 824, which ends method 800.

FIG. 9 is a flowchart illustrating an exemplary method 900 for fabricating a high-performance, high I/O ball grid array substrate for IC flip-chip assembly, having two patterned metal layer and one intermediate insulating layer, according to the teachings of the present invention. Method 900 begins at step 902 and proceeds next to step 904 where an insulating layer is provided that has a first surface and a second surface. Suitable materials include polyimides, epoxy glass (FR-4, FR-5, or BT), or other flexible electrically non-conductive materials; thickness usually in range 70 to 150  $\mu\text{m}$ .

At step 906, the insulating layer of the substrate is patterned to form a plurality of via holes using mechanical drilling or a laser beam technique. At step 908, the via holes are filled with metal, such as copper, or other electrically conductive material, creating a plurality of electrically conductive vias through the insulating layer of the substrate.

At step 910, one of the two metal layers (preferably copper, thickness between 7 to 15  $\mu\text{m}$ ) is attached to the first surface of the insulating layer (using typically a roll-on process). This metal layer is intended to provide electrical ground potential in the BGA. The patterning of

this metal layer, using standard photo-lithographic techniques, to form a plurality of electrically insulated openings intended for outside electrical contacts, such as solder balls, is performed at step 912.

5           At step 914, the other of the two metal layers (preferably copper, thickness between 7 to 15  $\mu\text{m}$ ) is attached to the second surface of the insulating layer (using typically a roll-on process). This metal layer is intended to provide three functions in three patterned  
10 portions. The patterning of this metal layer in step 916, using standard photo-lithographic techniques, creates the plurality of signal lines; the plurality of first power lines, providing a specific electrical potential; and the plurality of second power lines, providing another specific  
15 electrical potential. Selected signal and power lines are in electrical contact with the vias in the insulating layer.

          At step 918, insulating protective films are formed over the exposed surface of the ground layer and over the  
20 exposed surfaces of the signal and power lines. At step 920, pluralities of openings are formed in both insulating films; these openings are then filled with solderable metal (for instance, copper with gold flash), creating attachment sites for outside solder balls used in board attach, and  
25 for chip solder bumps used in flip-chip assembly. The fabrication of the BGA substrate is thus completed.

          In order to finish the fabrication of the BGA package, method 900 continues at step 922 by attaching an IC chip to the substrate. The chip has an active surface  
30 including solder bumps. These bumps are adhered to the plurality of metal-filled openings in the outermost insulating film protecting the signal and power lines. The

solder reflow typically involves the temperature of the eutectic tin/lead mixture.

The process flow chart continues at step 924 or, if needed, at step 923. At step 923, any gaps are filled  
5 between the substrate and the chip left void after the chip solder bumps have been adhered to the plurality of openings in the outermost insulating film protecting the signal and power lines. As filling material, a polymeric encapsulant is commonly used made of an epoxy-based precursor filled  
10 with silica and anhydrides, requiring elevated temperatures for curing.

At step 924, the chip (more precisely, the passive surface of the chip and its four edge sides) is surrounded with a polymeric encapsulation compound; preferably, a  
15 transfer molding process is used.

Due to the short thermal paths for heat dissipation, the thermal characteristics of the BGA of the invention are excellent. If further improvement is required, a heat slug can be attached in step 925; it is preferably positioned on  
20 the outer surface of the cured encapsulation material.

At step 926, solder balls are attached to the plurality of metal-filled openings in the outermost insulating film protecting the ground layer. This process provides external electrical and mechanical connections to  
25 the BGA package. Generally, the solder balls will be arrayed in a rectangular pattern around the periphery of the BGA package; a multitude of balls may also be positioned in the center of the package. Method 900 ends at step 928.

30 While this invention has been described in reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various

modifications and combinations of the illustrative  
embodiments, as well as other embodiments of the invention,  
will be apparent to persons skilled in the art upon  
reference to the description. As an example, the material  
5 of the semiconductor chip may comprise silicon, silicon  
germanium, gallium arsenide, or any other semiconductor  
material used in manufacturing. As another example, the  
BGA may have an encapsulation made by overmolding or  
another technique, or may have no encapsulation of the  
10 flip-soldered chip at all. As another example, instead of  
the encapsulation using molding compounds, a thermally  
conductive lead may be attached over the flip-soldered chip  
for physical protection and thermal enhancement. As  
another example, the two metal layers may be attached to  
15 the surfaces of the insulating layer concurrently and then  
patterned individually, rather than being attached and  
patterned sequentially. It is therefore intended that the  
appended claims encompass any such modifications or  
embodiments.

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WE CLAIM:

1. A high-performance, high I/O ball grid array substrate,  
designed for integrated circuit flip-chip assembly and  
5 having two patterned metal layers, comprising:
  - an insulating layer having a first surface, a second  
surface and a plurality of vias filled with  
metal;
  - 10 said first surface having one of said metal layers  
attached to provide electrical ground potential,  
and having a plurality of electrically insulated  
openings for outside electrical contacts;
  - an outermost insulating film protecting the exposed  
surface of said ground layer, said film having a  
15 plurality of openings filled with metal suitable  
for solder ball attachment;
  - said second surface having the other of said metal  
layers attached, portions thereof being  
configured as a plurality of electrical signal  
20 lines, further portions as a plurality of first  
electrical power lines, and further portions as a  
plurality of second electrical power lines,  
selected signal and power lines being in contact  
with said vias;
  - 25 said signal lines being distributed relative to said  
first power lines such that the inductive  
coupling between them reaches at least a minimum  
value, providing high mutual inductances and  
minimized effective self-inductance;
  - 30 said signal lines further being electromagnetically  
coupled to said ground metal such that cross-talk  
between signal lines is minimized; and

- an outermost insulating film protecting the exposed surfaces of said signal and power lines, said film having a plurality of openings filled with metal suitable for contacting selected signal and power lines and chip solder bumps.
2. The substrate according to Claim 1 wherein the number of said I/O's ranges from about 100 to about 600.
  3. The substrate according to Claim 1 wherein the thickness of said substrate is in the range from about 150 to 300  $\mu\text{m}$ .
  4. The substrate according to Claim 1 wherein said signal lines have a width between about 25 to 60  $\mu\text{m}$  and are spaced to an adjacent line by insulating material of about 20 to 50  $\mu\text{m}$  width.
  5. The substrate according to Claim 1 wherein said first power lines have a width from about 200 to 500  $\mu\text{m}$ .
  6. The substrate according to Claim 1 wherein said signal lines are positioned in a proximity of about 20 to 50  $\mu\text{m}$  to said first power lines, thus providing strong electromagnetic coupling, high mutual inductance and minimized effective self-inductance.
  7. The substrate according to Claim 1 wherein said signal lines are positioned to provide strong electromagnetic coupling to power and ground lines and thus minimal coupling, or cross-talk, between said signal lines.
  8. The substrate according to Claim 1 wherein said patterned metal layers are selected from a group consisting of copper, brass, aluminum, silver, or alloys thereof, and have a thickness in the range from about 7 to 15  $\mu\text{m}$ .
  9. The substrate according to Claim 1 wherein said insulating layer is made of organic material and is



selected from a group consisting of polyimide, polymer strengthened by glass fibers, FR-4, FR-5, and BT resin; said insulating layer having a thickness between about 70 and 150  $\mu\text{m}$ .

- 5 10. The substrate according to Claim 1 wherein said vias are filled with copper, tungsten, or any other electrically conductive material.
11. The substrate according to Claim 1 wherein said second power lines are structured as distributed areas having  
10 wide geometries for minimizing self-inductance and merging into a central area supporting said chip.
12. The substrate according to Claim 1 wherein said outermost insulating films are glass-filled epoxies, polyimides, acrylics or other photo-imageable materials  
15 suitable as solder masks and have a thickness between about 50 and 100  $\mu\text{m}$ .
13. The substrate according to Claim 1 wherein said openings for solder bump and solder ball attachments are made of copper including a flash of gold or  
20 palladium, or other wettable and solderable metals.
14. A high-performance, high I/O ball grid array package comprising:
  - a substrate having two patterned metal layers,  
comprising:
    - 25 an insulating layer having a first surface, a second surface and a plurality of vias filled with metal;
    - said first surface having one of said metal layers attached to provide electrical ground potential, and having a plurality of  
30 electrically insulated openings for outside electrical contacts;

an outermost insulating film protecting the  
exposed surface of said ground layer, said  
film having a plurality of openings filled  
with metal suitable for solder ball  
5 attachment;  
said second surface having the other of said  
metal layers attached, portions thereof being  
configured as a plurality of electrical signal  
lines, further portions as a plurality of  
10 first electrical power lines, and further  
portions as a plurality of second electrical  
power lines, selected signal and power lines  
being in contact with said vias;  
said signal lines being distributed relative to  
15 said first power lines such that the inductive  
coupling between them reaches at least a  
minimum value, providing high mutual  
inductances and minimized effective self-  
inductance;  
20 said signal lines further being  
electromagnetically coupled to said ground  
metal such that cross-talk between signal  
lines is minimized; and  
an outermost insulating film protecting the  
25 exposed surfaces of said signal and power  
lines, said film having a plurality of  
openings filled with metal suitable for  
contacting selected signal and ground lines  
and chip solder bumps;  
30 an integrated circuit chip having an active surface  
including solder bumps, said solder bumps adhered  
to said plurality of openings in said outermost

- insulating film protecting said signal and power lines; and
- solder balls attached to said plurality of openings in said outermost insulating film protecting said ground layer.
- 5
15. The package according to Claim 14 further comprising a polymeric encapsulant filling any gaps between said chip and said substrate, left void after said chip solder bumps are adhered to said plurality of openings in said outermost insulating film protecting said signal and power lines.
- 10
16. The package according to Claim 15 wherein said polymeric encapsulant is a polymeric precursor made of an epoxy base material filled with silica and anhydrides, requiring thermal energy for curing to form a polymeric encapsulant.
- 15
17. The package according to Claim 14 further comprising an encapsulation material surrounding said chip.
18. The package according to Claim 17 wherein said encapsulation material is a polymeric material selected from a group consisting of epoxy-based molding compounds suitable for adhesion to said chip, and fluoro-dielectric compounds supporting high-speed and high-frequency package performance.
- 20
19. The package according to Claim 17 further comprising an optional heat spreader positioned on the outer surface of said encapsulation material.
- 25
20. The package according to Claim 14 wherein said chip solder bumps comprise attach materials selected from a group consisting of tin, lead/tin alloys, indium, indium/tin alloys, solder paste, and conductive adhesive compounds.
- 30

21. The package according to Claim 14 wherein said solder balls comprise attach materials selected from a group consisting of tin/lead, tin/indium, tin/silver, tin/bismuth, solder paste, and conductive adhesive compounds.
22. The package according to Claim 14 wherein the thickness of said package is in the range from about 250 to 800  $\mu\text{m}$ , excluding the thickness of the heat slug.
23. A computer-implemented method for modeling a high-performance, high I/O ball grid array substrate, intended for integrated circuit flip-chip assembly and having a first and a second metal layer and one intermediate insulating layer, all of substantially equal areas, comprising the steps of:
- modeling the structure of said first metal layer as electrical ground potential, said layer having a plurality of electrically insulated openings for electrical contacts;
  - modeling the structure of said second metal layer as a plurality of electrical signal lines, a plurality of first electrical power lines operable at a first potential, and a plurality of second electrical power lines operable at a second potential;
  - configuring said first power lines so wide that their combined inductances approximate the inductance of a metal having the size of the total substrate;
  - concurrently distributing said first power lines among said signal lines in order to provide at least minimum inductive coupling between signal and power lines, thereby obtaining high mutual

inductances and minimizing effective self-inductance;

5 configuring said second power lines to serve as distributed areas having wide geometries for minimizing self-inductance and merging into a central area supporting said chip; and modeling the structure of said insulating layer for positioning it between said first and second metal layers, and selecting its thickness and material characteristics suitable for strong  
10 electromagnetic coupling between said signal lines and said first metal layer, thereby providing a predetermined impedance to ground and minimizing cross-talk between signal lines.

15 24. A method for fabricating a high performance, high I/O ball grid array substrate, intended for two patterned metal layers and integrated circuit flip-chip assembly, comprising the steps of:

20 providing an electrically insulating layer having a first and a second surface;

forming a plurality of via holes in said insulating layer and filling said holes with electrically conductive material;

25 attaching one of said metal layers to said first surface, said metal layer intended to provide electrical ground potential;

forming a plurality of electrically insulated openings in said metal layer, said openings intended for outside electrical contacts;

30 attaching the other of said metal layers to said second surface, said metal layer intended to provide electrical signal and power potentials;

configuring portions of said metal layer as a plurality of electrical signal lines, further portions as a plurality of first electrical power lines, and further portions as a plurality of second electrical power lines, thereby creating contact between selected signal and power lines and said vias;

forming an insulating protective film over the exposed surface of said ground layer, and an insulating film over the exposed surfaces of said signal and power lines; and

forming pluralities of openings in both said insulating films, and filling said openings with solderable metal, thereby creating attachment sites for outside solder balls and for chip solder bumps.

25. The method according to Claim 24 further comprising the step of attaching an integrated circuit chip, having an active surface including solder bumps, by adhering said solder bumps to said plurality of metal-filled openings in said outermost insulating film protecting said signal and power lines.

26. The method according to Claim 25 further comprising the step of filling with a polymeric encapsulant any gaps between said substrate and said chip left void after said chip solder bumps are adhered to said plurality of openings in said outermost insulating film protecting said signal and power lines.

27. The method according to Claim 24 further comprising the step of surrounding said chip with a polymeric encapsulation compound.

28. The method according to Claim 27 further comprising the

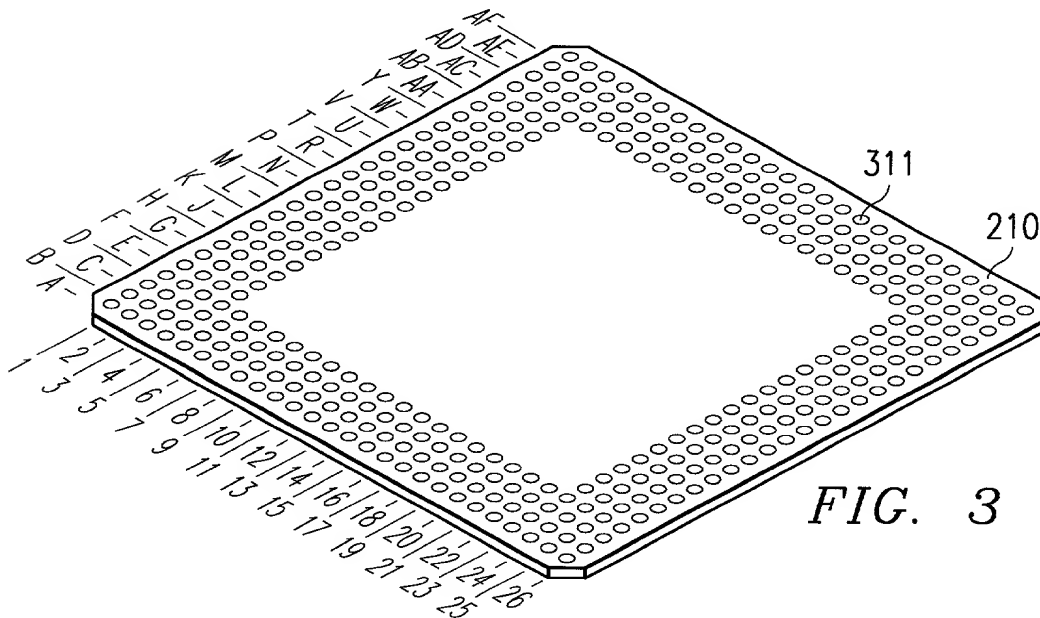
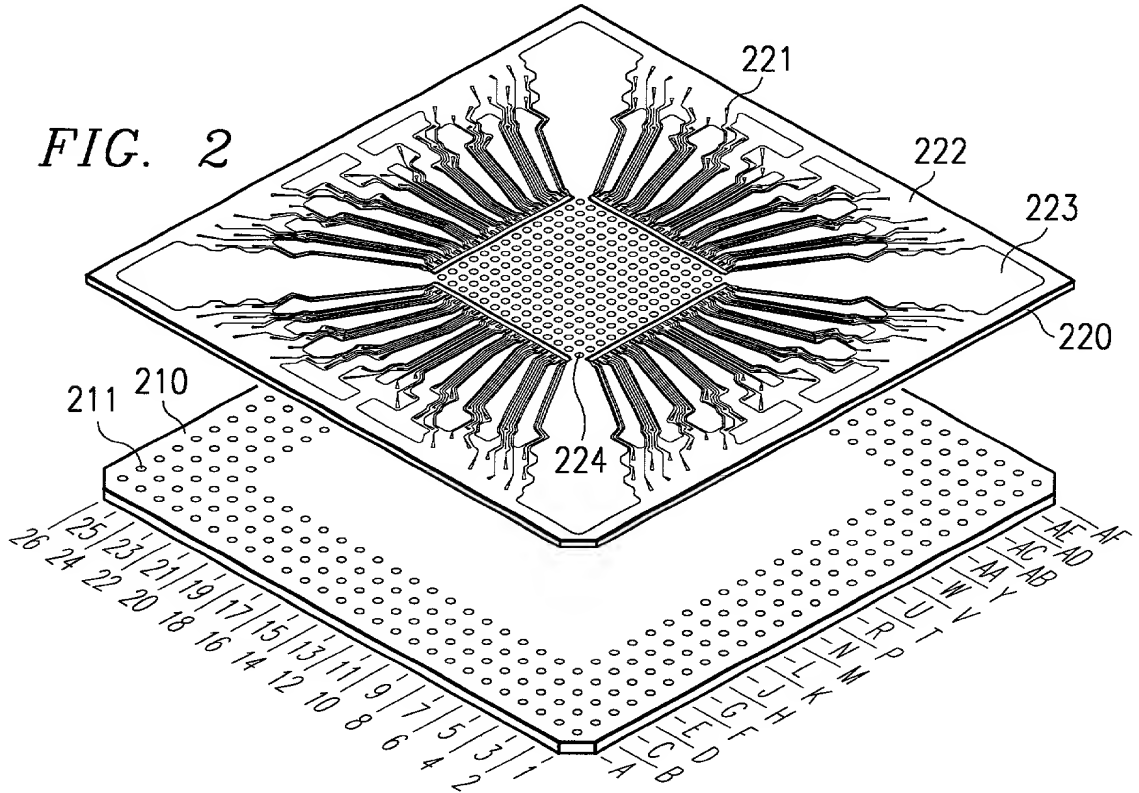
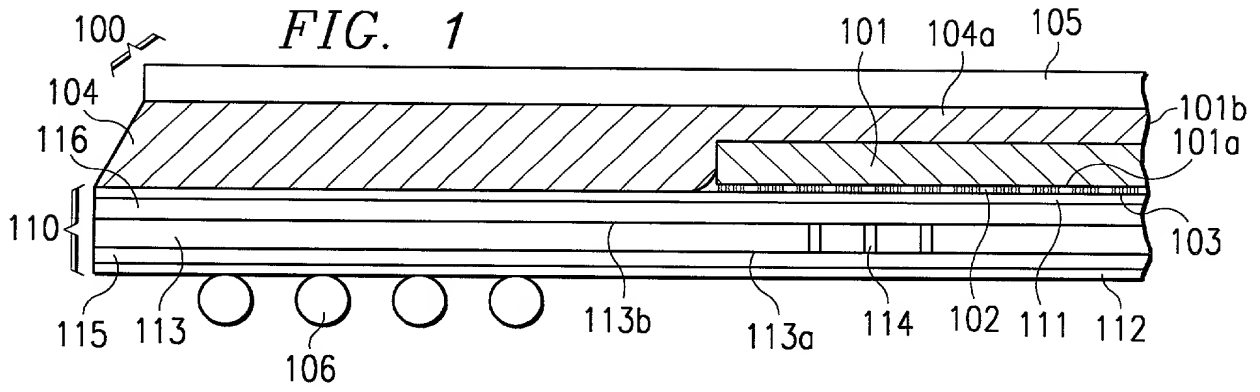
step of attaching a heat spreader positioned on the  
outer surface of said encapsulation material.

29. The method according to Claim 24 further comprising the  
step of attaching solder balls to said plurality of  
5 metal-filled openings in said outermost insulating film  
protecting said ground layer.

## ABSTRACT

A high-performance, high I/O ball grid array substrate, designed for integrated circuit flip-chip assembly and having two patterned metal layers, comprising:  
5 an insulating layer having a first surface, a second surface and a plurality of vias filled with metal. Said first surface having one of said metal layers attached to provide electrical ground potential, and having  
10 a plurality of electrically insulated openings for outside electrical contacts. An outermost insulating film protecting the exposed surface of said ground layer, said film having a plurality of openings filled with metal suitable for solder ball attachment. Said second surface  
15 having the other of said metal layers attached, portions thereof being configured as a plurality of electrical signal lines, further portions as a plurality of first electrical power lines, and further portions as a plurality of second electrical power lines, selected signal  
20 and power lines being in contact with said vias. Said signal lines being distributed relative to said first power lines such that the inductive coupling between them reaches at least a minimum value, providing high mutual inductances and minimized effective self-inductance. Said signal lines  
25 further being electromagnetically coupled to said ground metal such that cross talk between signal lines is minimized. And an outermost insulating film protecting the exposed surfaces of said signal and power lines, said film having a plurality of openings filled with metal suitable  
30 for contacting selected signal and power lines and chip solder bumps.





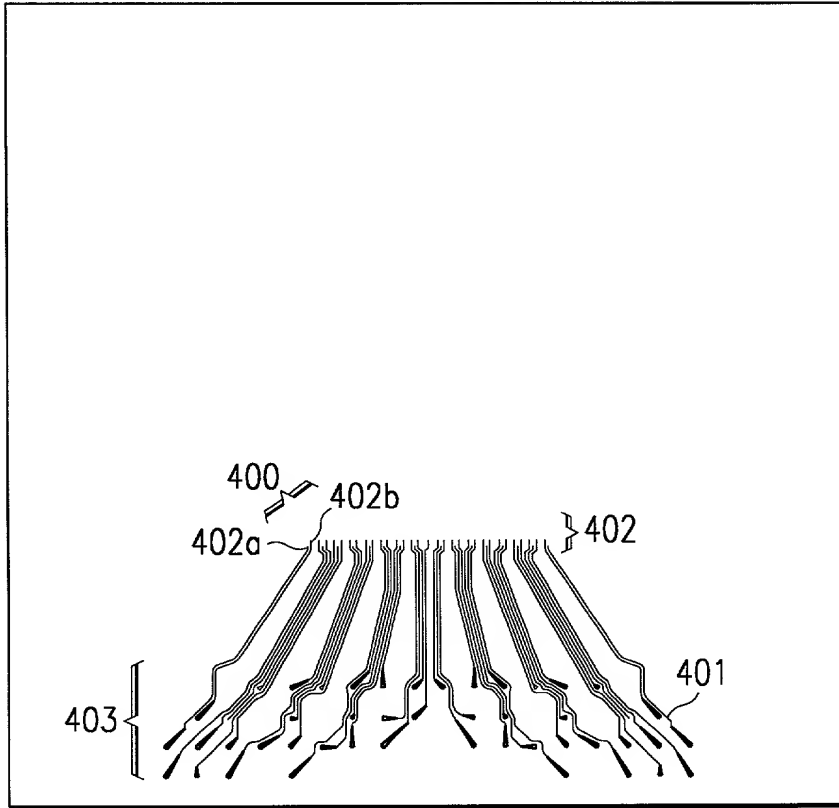


FIG. 4

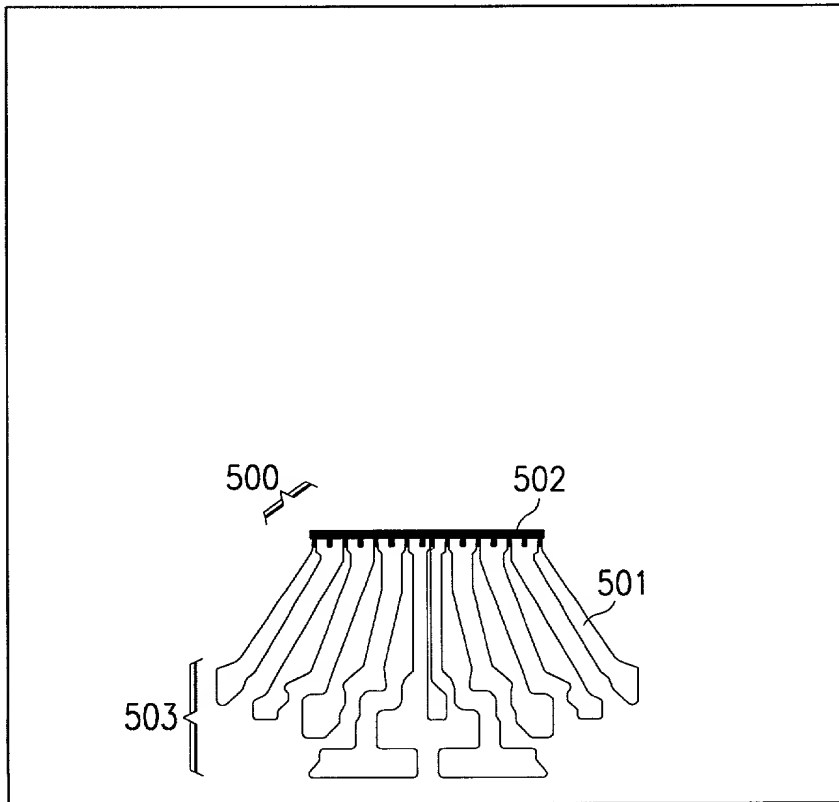


FIG. 5

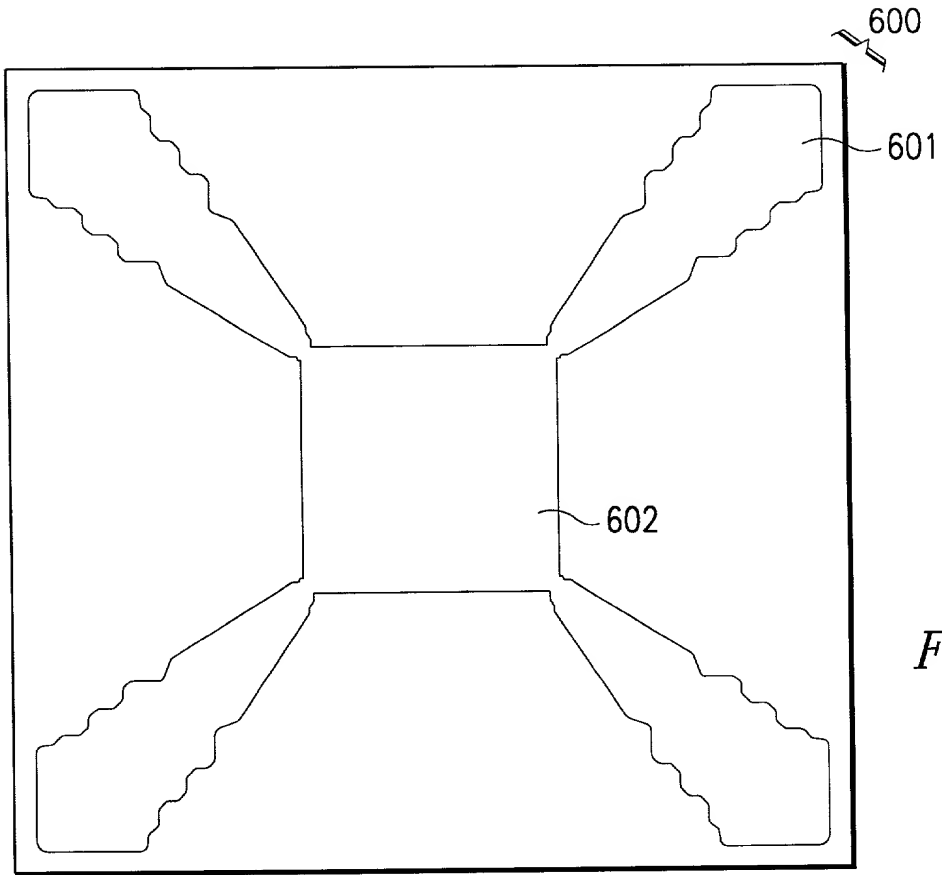


FIG. 6

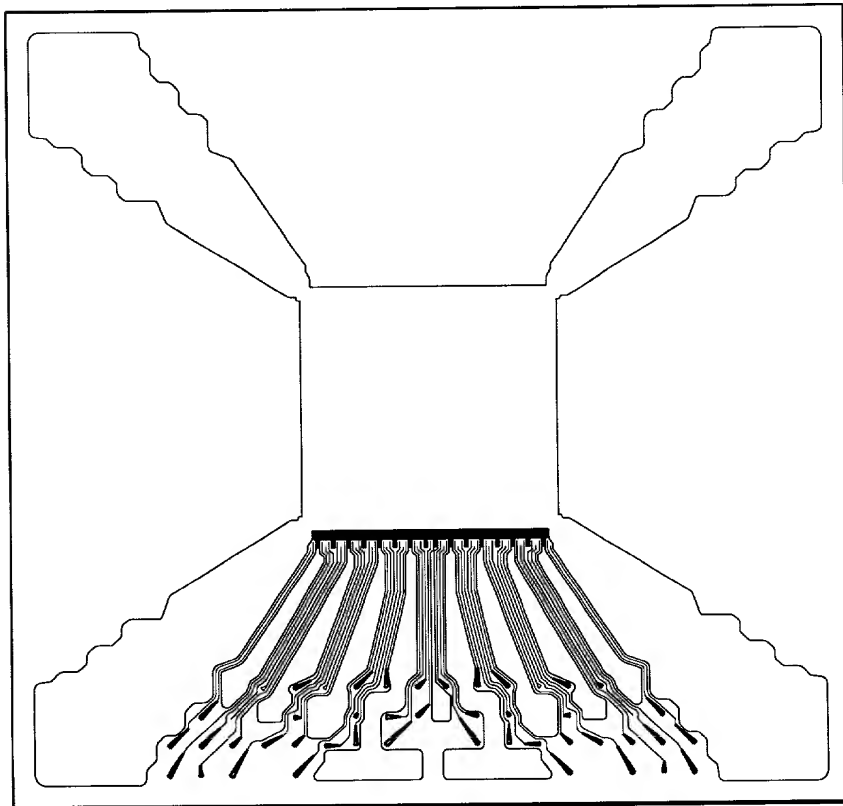
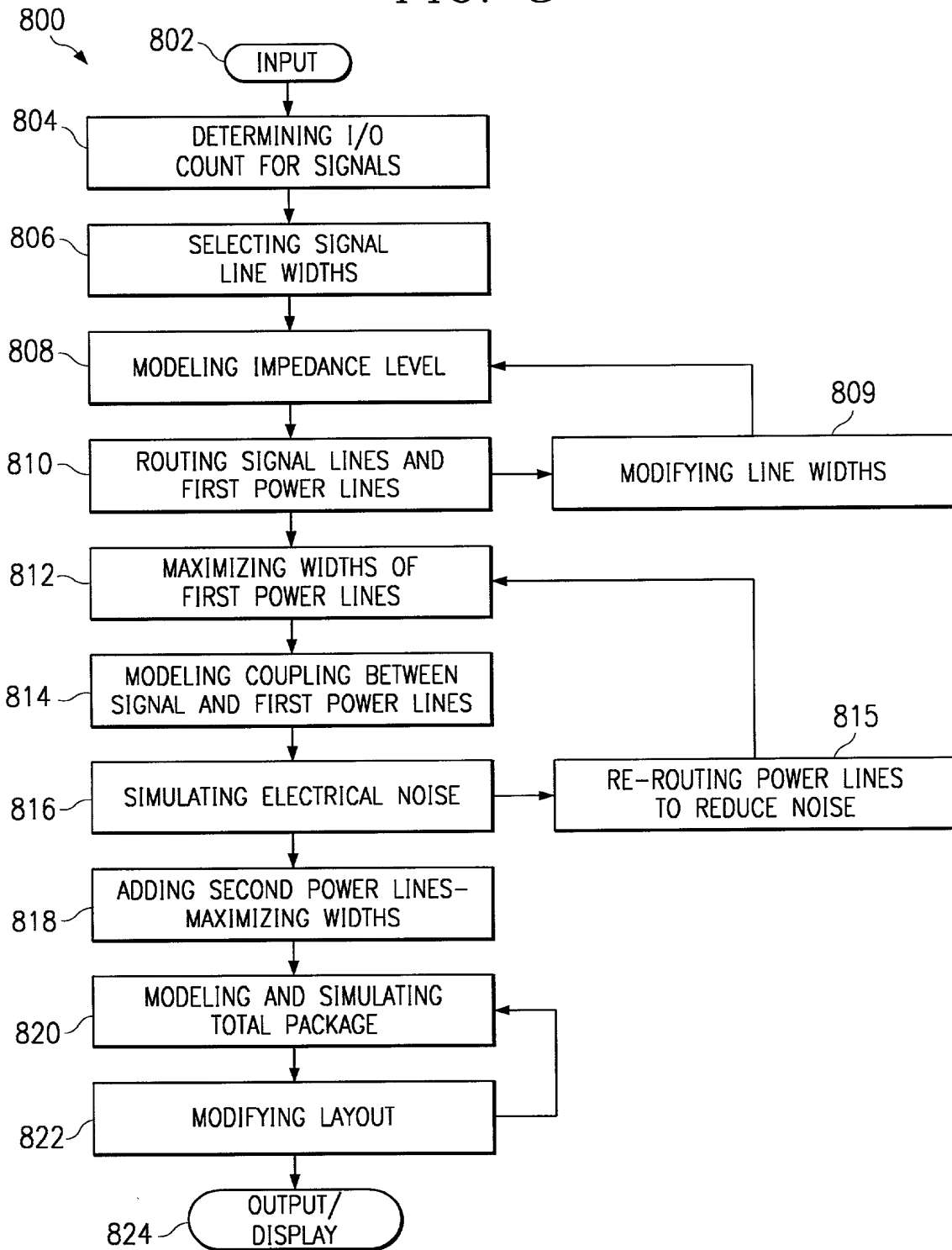


FIG. 7

FIG. 8



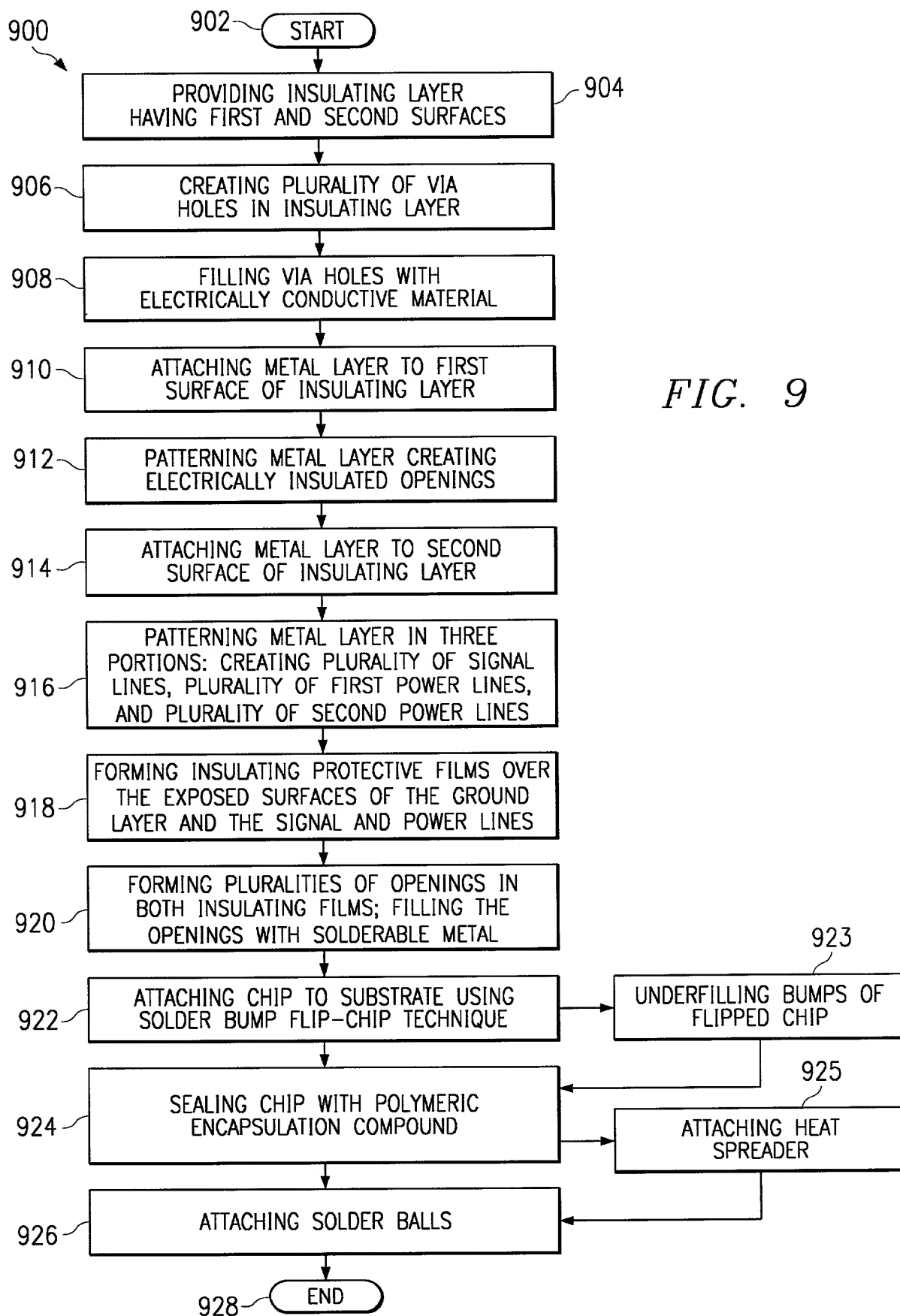


FIG. 9

PAGE 1 OF 1

# **APPLICATION FOR UNITED STATES PATENT DECLARATION AND POWER OF ATTORNEY**

As a below named inventor, I declare that my residence, post office address and citizenship are as stated below next to my name; that I verily believe that I am the original, first and sole inventor if only one name is listed below, or an original, first and joint inventor if plural inventors are named below, of the subject matter which is claimed and for which a patent is sought on the invention entitled as set forth below, which is described in the attached specification; that I have reviewed and understand the contents of the specification, including the claims, as amended by any amendment specifically referred to in the oath or declaration; that no application for patent or inventor's certificate on this invention has been filed by me or my legal representatives or assigns in any country foreign to the United States of America; and that I acknowledge my duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56;

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

**TITLE OF INVENTION:**

Structure and Method of High Performance Two Layer Ball Grid Array Substrate

**POWER OF ATTORNEY:** I HEREBY APPOINT THE FOLLOWING ATTORNEYS TO PROSECUTE THIS APPLICATION AND TRANSACT ALL BUSINESS IN THE PATENT AND TRADEMARK OFFICE CONNECTED THEREWITH

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**COUNTRY OF CITIZENSHIP:****SIGNATURE OF INVENTOR:**

**SIGNATURE OF INVENTOR:**

**SIGNATURE OF INVENTOR:****DATE:**

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**DATE:**

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